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(54) **SUSPENSION SYSTEM FOR AUTONOMOUS TRANSPORTS**

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(58) **Field of Classification Search**

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See application file for complete search history.

(73) Assignee: **Symbotic, LLC**, Wilmington, MA (US)

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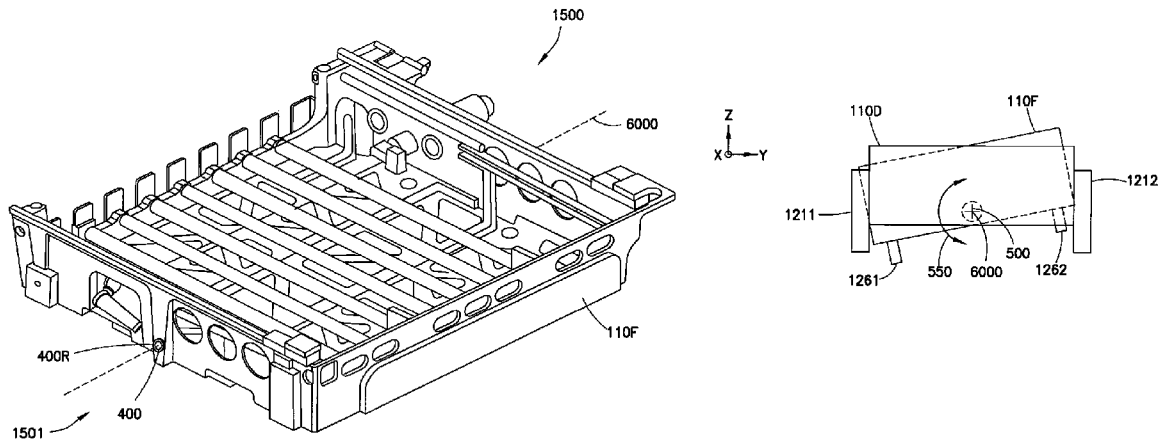
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(57)

ABSTRACT

An autonomous transport robot for transporting a payload, the autonomous transport robot including a drive section assembly having at least one motor and a pair of drive wheels coupled to the motor, a frame configured to support a payload, a transfer arm connected to the frame and configured for the autonomous transfer of payload to and from the frame, and a suspension system movably connecting the drive section assembly and the frame allowing relative movement between the frame and the drive section assembly.

27 Claims, 11 Drawing Sheets



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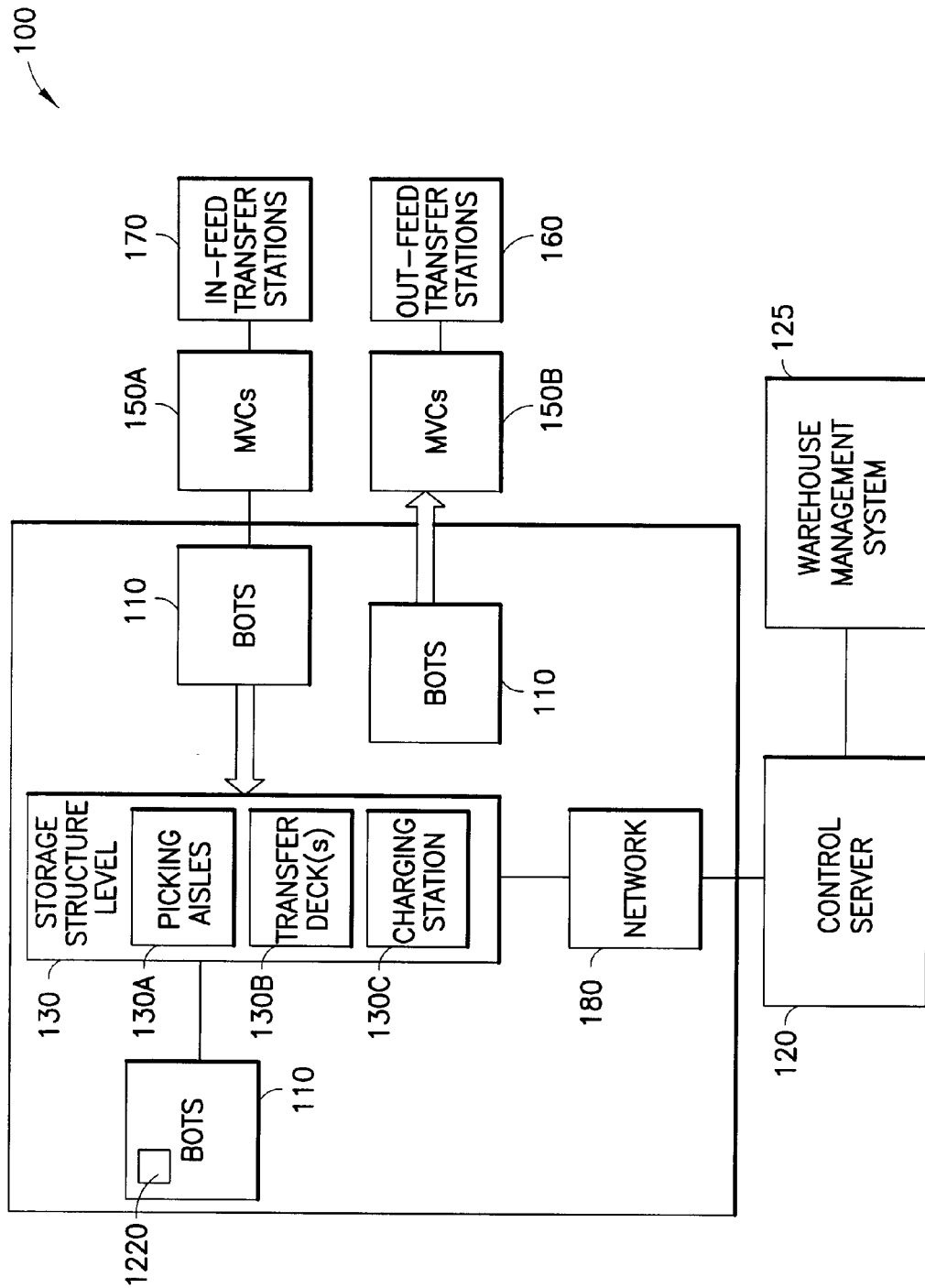


FIG. 1

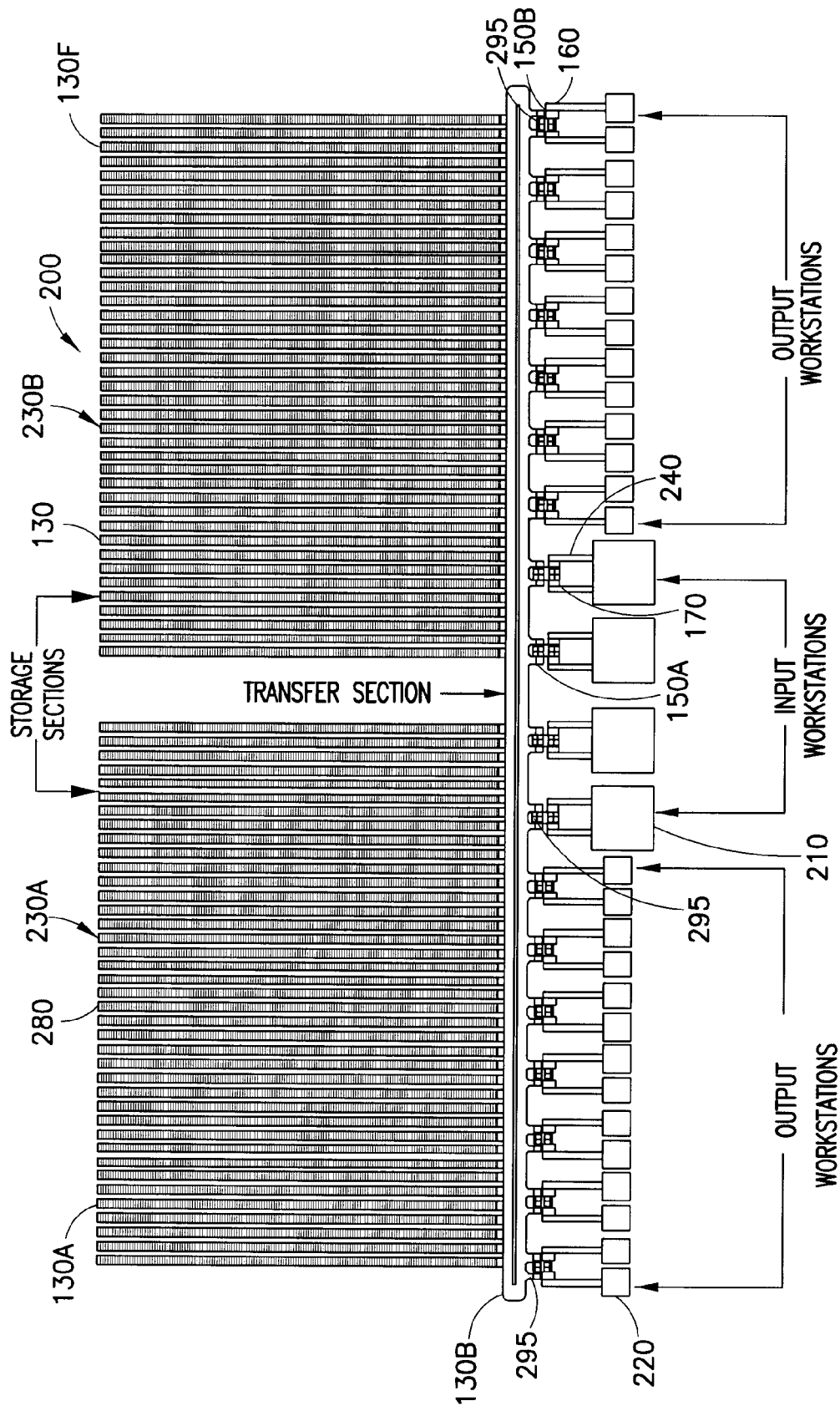


FIG. 2

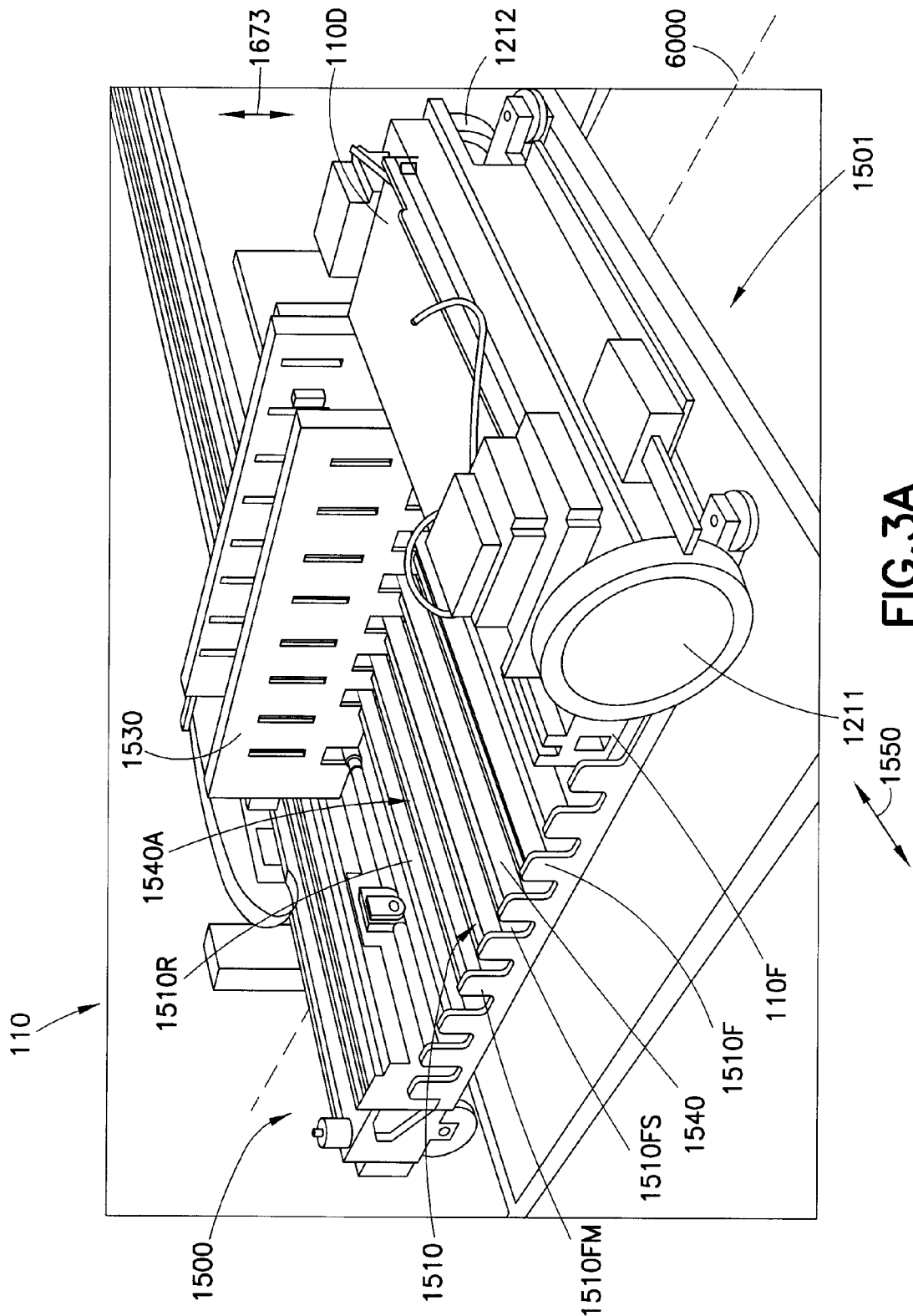


FIG. 3A

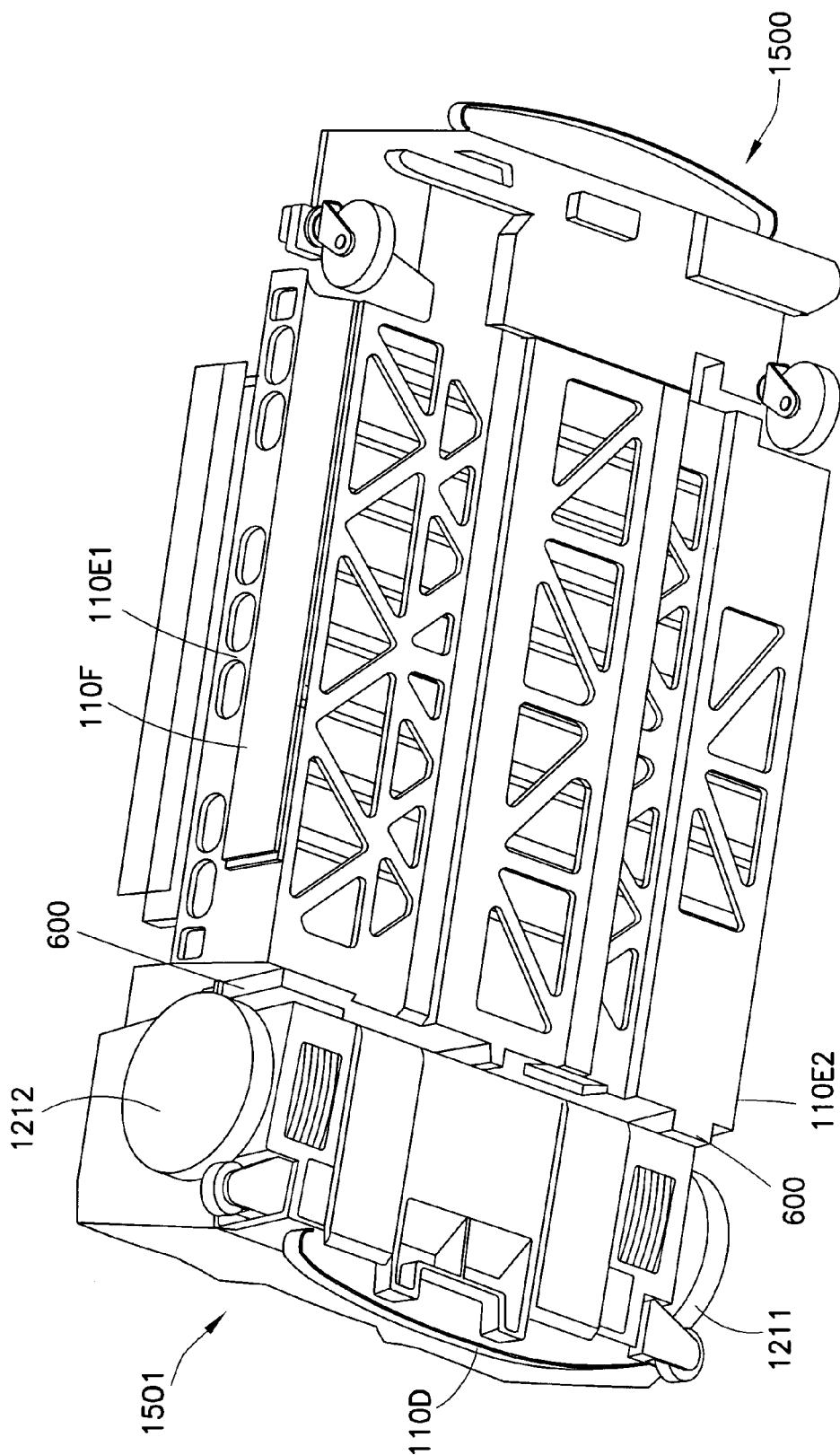


FIG. 3B

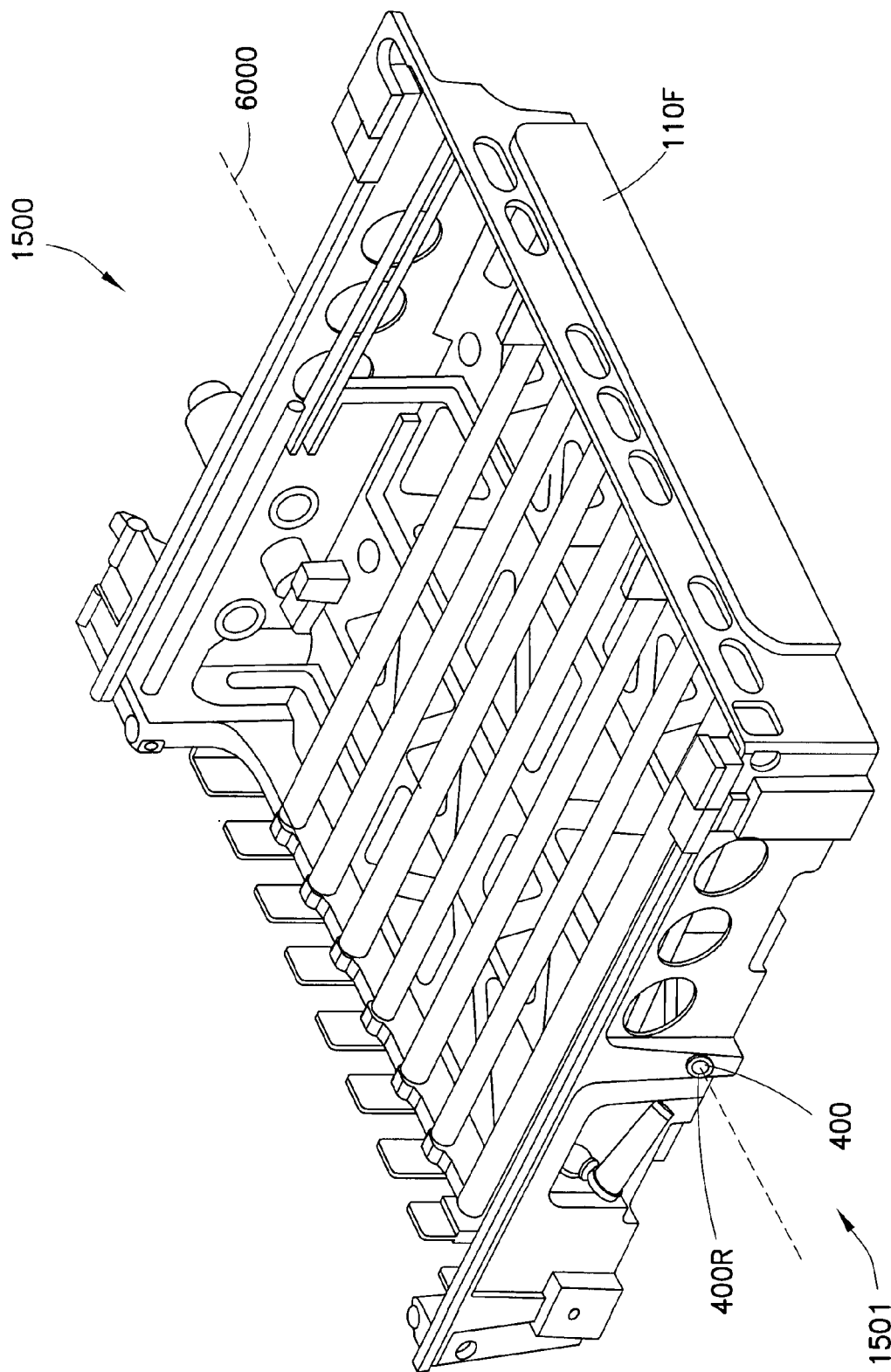
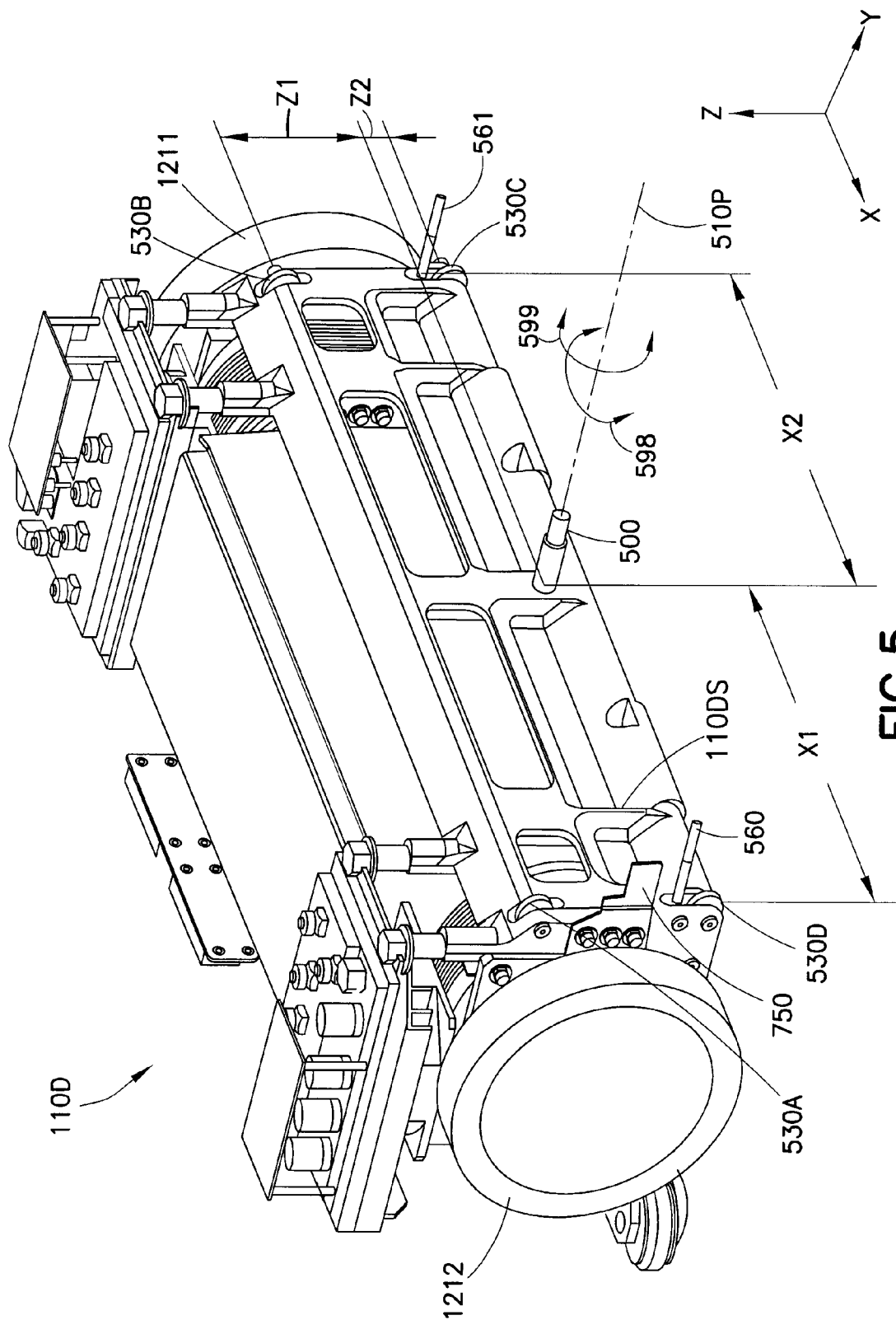


FIG. 4



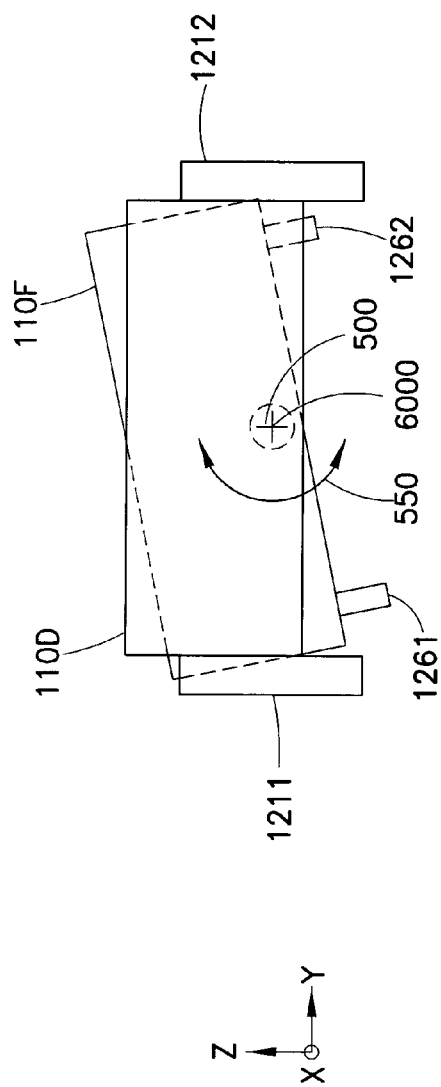


FIG. 5A

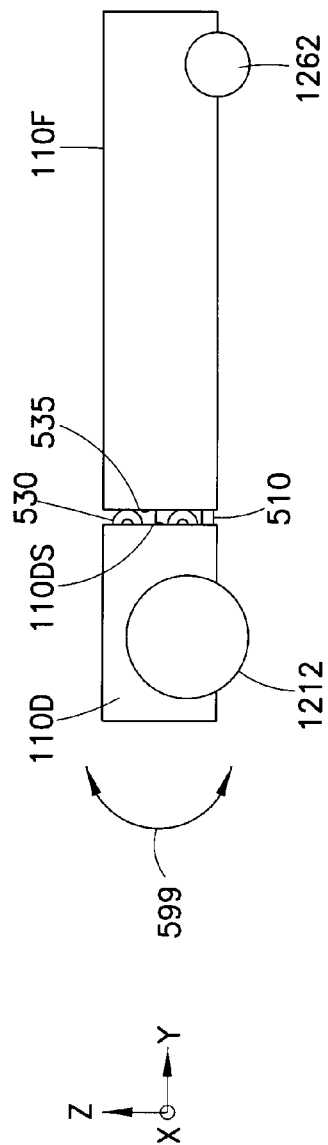


FIG. 5B

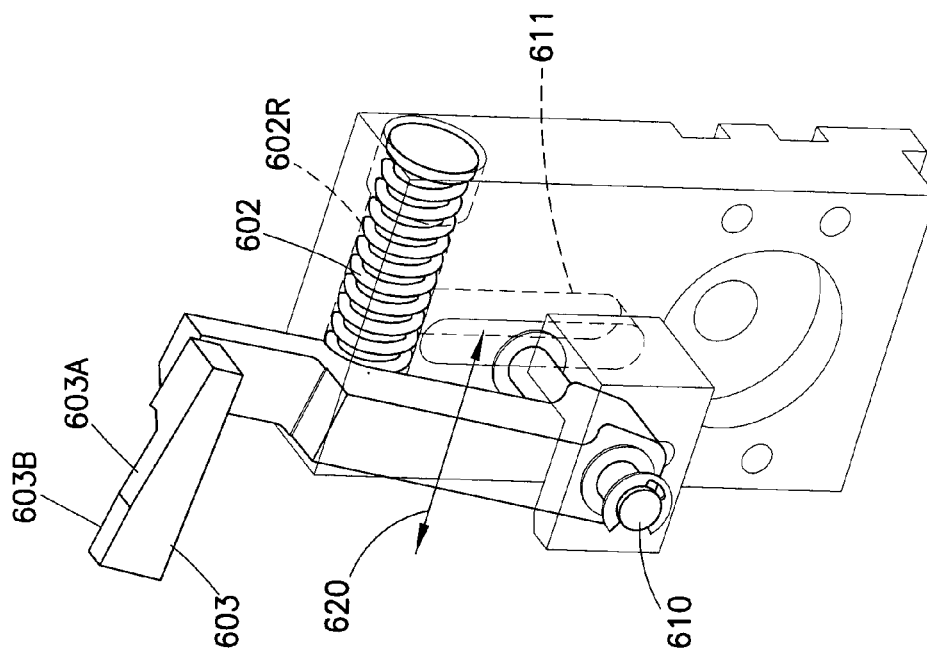


FIG. 6A

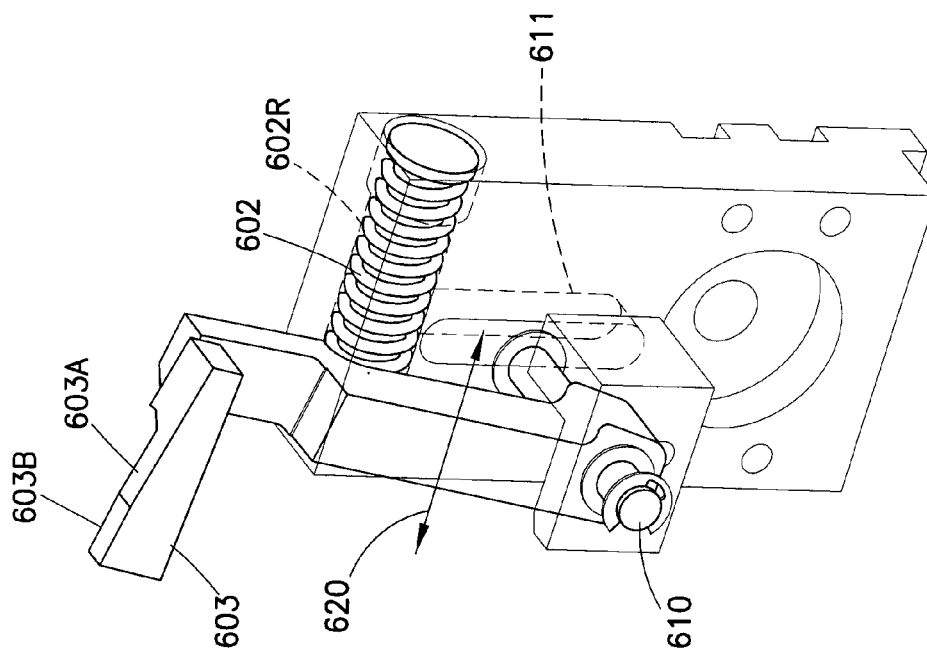


FIG. 6B

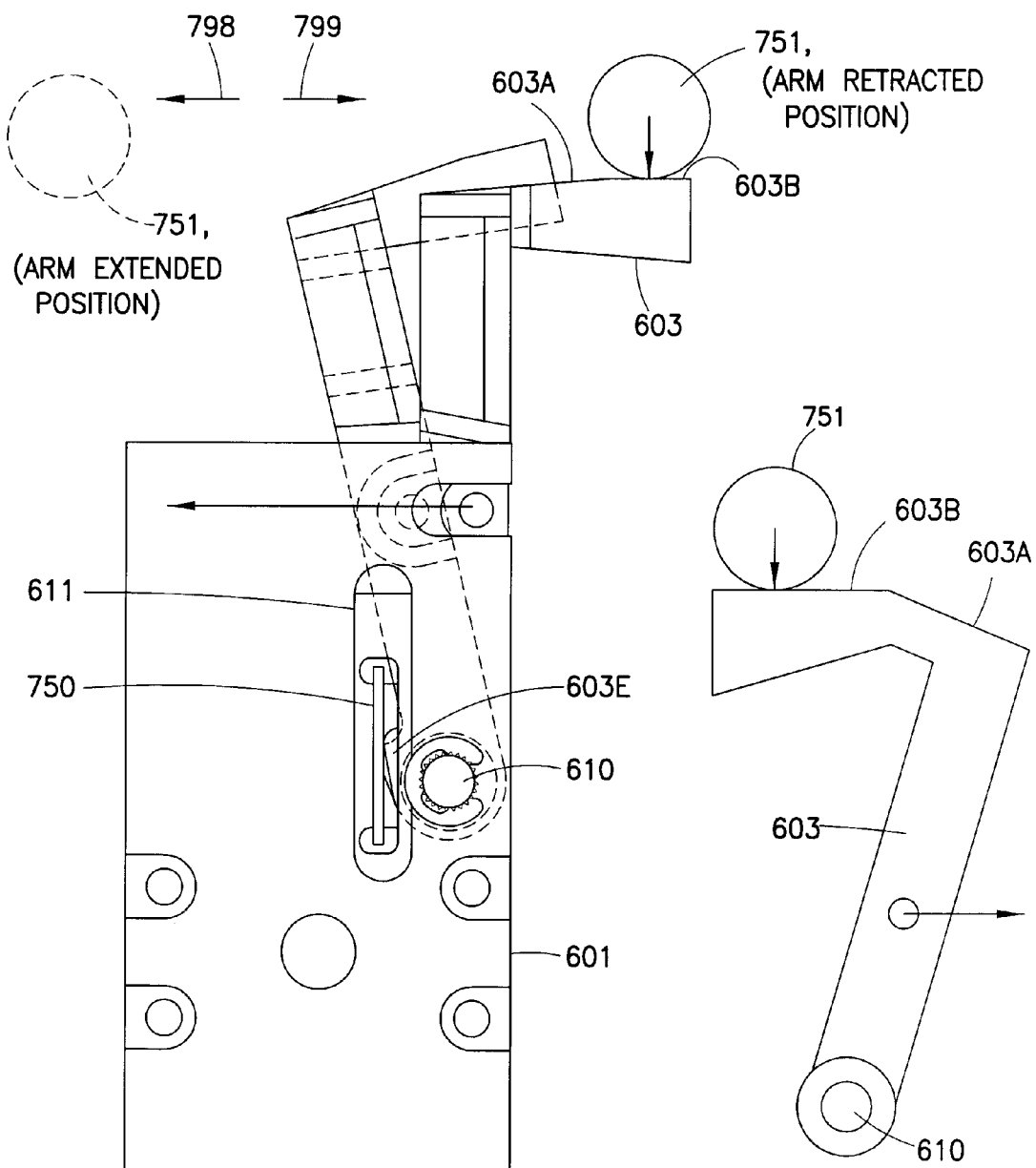


FIG. 6C

FIG. 6D

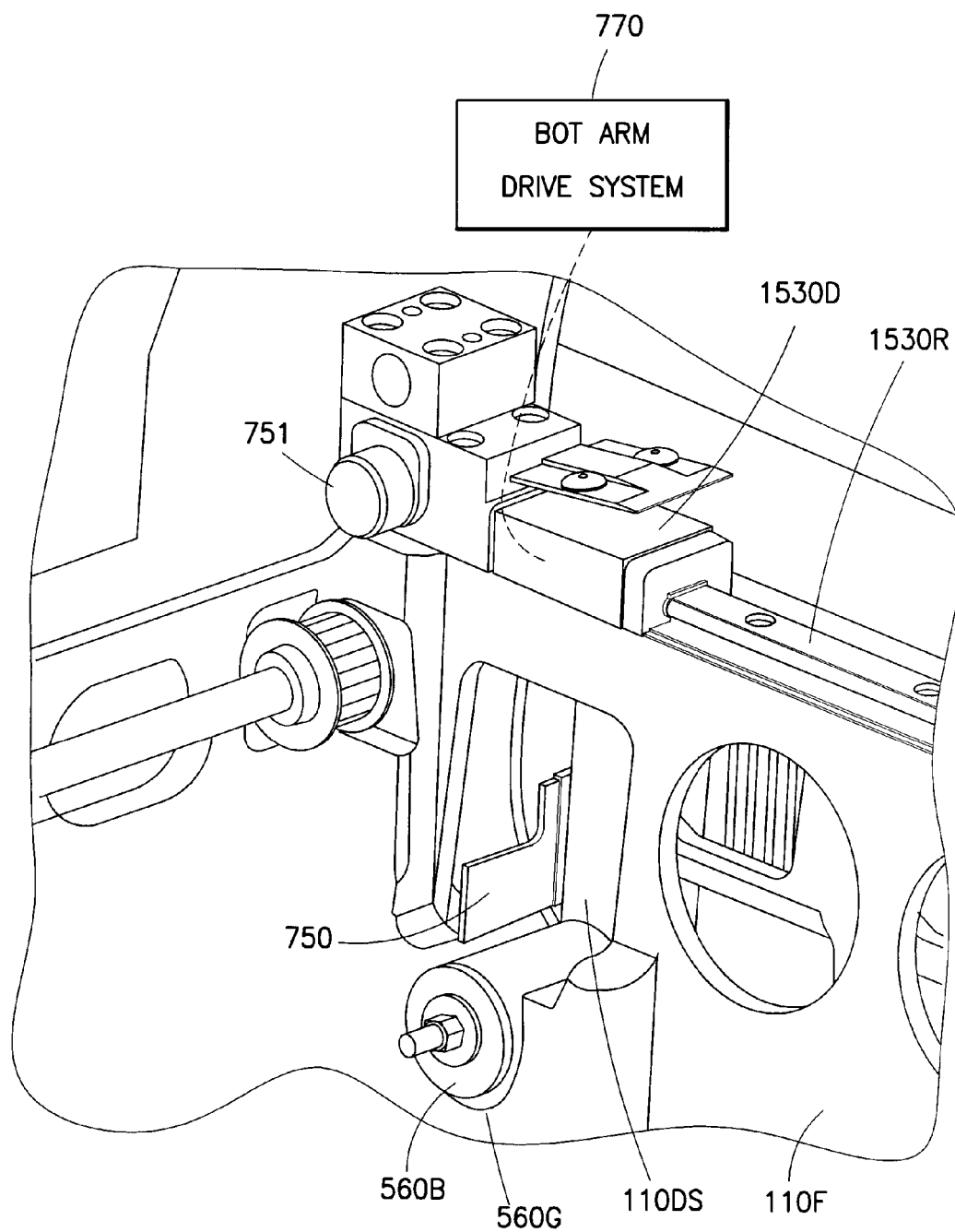


FIG. 7A

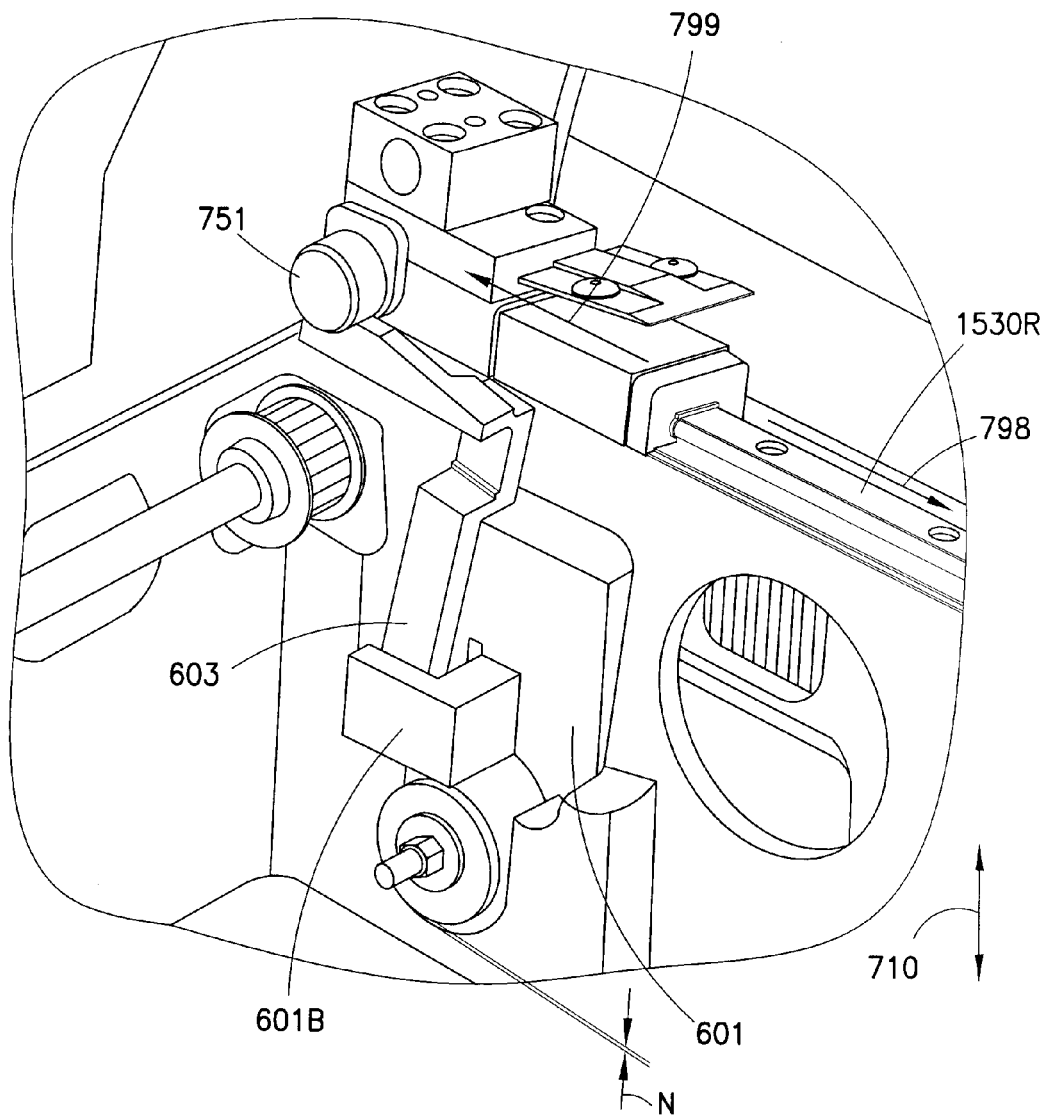


FIG. 7B

1

SUSPENSION SYSTEM FOR AUTONOMOUS TRANSPORTS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 14/245,551 filed on Apr. 4, 2014 which is a continuation of U.S. patent application Ser. No. 13/326,505 filed on Dec. 15, 2011 (now U.S. Pat. No. 8,696,010) which is a non-provisional of and claims the benefit of U.S. provisional patent application Ser. No. 61/423,317 filed on Dec. 15, 2010, the disclosures of which are incorporated by reference herein in their entireties.

BACKGROUND

1. Field

The embodiments generally relate to storage and retrieval systems and, more particularly, to autonomous transports of the storage and retrieval systems.

2. Brief Description of Related Developments

Warehouses for storing case units may generally comprise a series of storage racks that are accessible by transport devices such as, for example, fork lifts, carts and elevators that are movable within aisles between or along the storage racks or by other lifting and transporting devices. These transport devices may be automated or manually driven. Generally the surfaces over which the transport devices operate may have uneven surfaces.

When transporting the cases to and from the storage racks with automated transports it would be advantageous to keep the wheels of the automated transports in substantial contact with the surfaces of the travel decks.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects and other features of the disclosed embodiments are explained in the following description, taken in connection with the accompanying drawings, wherein:

FIG. 1 schematically illustrates an exemplary storage and retrieval system in accordance with the embodiments;

FIG. 2 illustrates a schematic plan view of an exemplary storage and retrieval system in accordance with the embodiments;

FIGS. 3A and 3B are schematic illustrations of an exemplary autonomous transport vehicle in accordance with the embodiments;

FIG. 4 is a schematic illustration of a portion of the autonomous transport vehicle of FIG. 3 in accordance with the embodiments;

FIG. 5 is a schematic illustration of a portion of the autonomous transport vehicle of FIG. 3 in accordance with the embodiments;

FIGS. 5A and 5B are schematic illustrations of the autonomous transport vehicle of FIG. 3 in accordance with the embodiments;

FIGS. 6A, 6B, 6C and 6D are schematic illustrations of a portion of the autonomous transport vehicle of FIG. 3 in accordance with the embodiments; and

FIGS. 7A and 7B are schematic illustrations of a portion the exemplary autonomous transport vehicle of FIG. 3 in accordance with the embodiments.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENT(S)

FIG. 1 schematically illustrates an exemplary storage and retrieval system in accordance with the embodiments.

2

Although the disclosed embodiments will be described with reference to the embodiments shown in the drawings, it should be understood that the disclosed embodiments can be embodied in many alternate forms. In addition, any suitable size, shape or type of elements or materials could be used.

In accordance with the embodiments the storage and retrieval system **100** may operate in a retail distribution center or warehouse to, for example, fulfill orders received from retail stores for case units (where case units as used herein means items not stored in trays, on totes or on pallets, e.g. uncontained or items stored in trays, totes or on pallets). It is noted that the case units may include cases of items (e.g. case of soup cans, boxes of cereal, etc.) or individual items that are adapted to be taken off of or placed on a pallet. In accordance with the embodiments, shipping cases or case units (e.g. cartons, barrels, boxes, crates, jugs, totes, pallets or any other suitable device for holding case units) may have variable sizes and may be used to hold items in shipping and may be configured so they are capable of being palletized for shipping. It is noted that when, for example, bundles or pallets of case units arrive at the storage and retrieval system the content of each pallet may be uniform (e.g. each pallet holds a predetermined number of the same item—one pallet holds soup and another pallet holds cereal) and as pallets leave the storage and retrieval system the pallets may contain any suitable number and combination of different items (e.g. each pallet may hold different types of items—a pallet holds a combination of soup and cereal). In the embodiments the storage and retrieval system described herein may be applied to any environment in which case units are stored and retrieved.

The storage and retrieval system **100** may be configured for installation in, for example, existing warehouse structures or adapted to new warehouse structures. In the embodiments, the storage and retrieval system may include in-feed and out-feed transfer stations **170**, **160**, multilevel vertical conveyors **150A**, **150B**, a storage structure **130**, and a number of autonomous transport vehicles or robots **110** (referred to herein as “bots”). In the embodiments the storage and retrieval system may also include robot or bot transfer stations (as described in, for example, U.S. patent application Ser. No. 12/757,220, entitled “STORAGE AND RETRIEVAL SYSTEM,” the disclosure of which is incorporated by reference herein in its entirety) that may provide an indirect interface between the bots **110** and the multilevel vertical conveyor **150A**, **150B**. The in-feed transfer stations **170** and out-feed transfer stations **160** may operate together with their respective multilevel vertical conveyors **150A**, **150B** for bi-directionally transferring case units to and from one or more levels of the storage structure **130**. In the embodiments the multilevel vertical conveyors **150A**, **150B** may be dedicated inbound or in-feed conveyors **150A** and outbound or out-feed conveyors **150B**, or each of the conveyors **150A**, **150B** may be used for both inbound and outbound transfer of case units/items from the storage and retrieval system. The multilevel vertical conveyors may be any suitable lifting devices for transporting case units between levels of the storage and retrieval system. It is noted that while multilevel vertical conveyors are described herein in other aspects the conveyors may be any suitable conveyors or transfer/picking devices having any suitable transport path orientation. Some non-limiting suitable examples of a multilevel vertical conveyor can be found in, for example, U.S. Provisional Patent Application entitled “LIFT INTERFACE FOR STORAGE AND RETRIEVAL SYSTEMS” and filed on Dec. 15, 2010, U.S. patent application Ser. No. 12/757,354, entitled “LIFT INTERFACE FOR STORAGE AND RETRIEVAL SYSTEMS,” (the disclosure of which is incorporated by reference

herein in its entirety) and U.S. patent application Ser. No. 12/757,220, entitled "STORAGE AND RETRIEVAL SYSTEM," (previously incorporated by reference). For example, the multilevel vertical conveyors may have any suitable number of support shelves for transporting the case units to a predetermined level of the storage and retrieval system. The support shelves may have slatted supports configured to allow fingers of the bots **110** or in-feed/out-feed transfer stations **170**, **160** to pass between the slats for transferring case units to and from the conveyor. In alternate embodiments transfer of case units between the bots and the multilevel vertical conveyors may occur in any suitable manner.

As may be realized, the storage and retrieval system **100** may include multiple in-feed and out-feed multilevel vertical conveyors **150A**, **150B** that are accessible by, for example, bots **110** on each level of the storage and retrieval system **100** so that one or more case unit(s) can be transferred from a multilevel vertical conveyor **150A**, **150B** to each storage space on a respective level and from each storage space to any one of the multilevel vertical conveyors **150A**, **150B** on a respective level. The bots **110** may be configured to transfer the case units between the storage spaces and the multilevel vertical conveyors with one pick (e.g. substantially directly between the storage spaces and the multilevel vertical conveyors). By way of further example, the designated bot **110** picks the case unit(s) from a shelf of a multilevel vertical conveyor, transports the case unit(s) to a predetermined storage area of the storage structure **130** and places the case unit(s) in the predetermined storage area (and vice versa).

The bots **110** may be configured to place case units, such as the above described retail merchandise, into picking stock in the one or more levels of the storage structure **130** and then selectively retrieve ordered items for shipping the ordered items to, for example, a store or other suitable location. In one exemplary embodiment, the bots **110** may interface in any suitable manner with the multilevel vertical conveyors **150A**, **150B** such as through, for example, extension of a transfer arm or effector of the bot relative to a frame of the bot. Suitable examples of bots are described in U.S. patent application Ser. No. 12/757,312, entitled "AUTONOMOUS TRANSPORTS FOR STORAGE AND RETRIEVAL SYSTEMS" and filed on Apr. 9, 2010, U.S. Provisional Patent Application entitled "AUTOMATED BOT WITH TRANSFER ARM" (Ser. No. 61/423,365) and filed on Dec. 15, 2010 (now U.S. patent application Ser. No. 13/326,952 filed Dec. 15, 2011), U.S. Provisional Patent Application entitled "AUTOMATED BOT TRANSFER ARM DRIVE SYSTEM" (Ser. No. 61/423,388) and filed on Dec. 15, 2010 (now U.S. patent application Ser. No. 13/326,993 filed Dec. 15, 2011), U.S. Provisional Patent Application entitled "BOT HAVING HIGH SPEED STABILITY" (Ser. No. 61/423,359) and filed on Dec. 15, 2010 (now U.S. patent application Ser. No. 13/326,447 filed Dec. 15, 2011), and U.S. Provisional Patent Application entitled "BOT SENSING POSITION" (Ser. No. 61/423,206) and filed on Dec. 15, 2010 (now U.S. patent application Ser. No. 13/327,035 filed Dec. 15, 2011), the disclosures of which are incorporated by reference herein in their entireties.

The storage structure **130** may include multiple levels of storage rack modules where each level includes an array of storage spaces (arrayed on the multiple levels and in multiple rows on each level), picking aisles **130A** formed between the rows of storage spaces, and transfer decks **130B**. In the embodiments, each level may also include respective bot transfer stations for providing an indirect interface between the bots and the multilevel vertical conveyors. The picking aisles **130A** and transfer decks **130B** may be arranged for

allowing the bots **110** to traverse respective levels of the storage structure **130** for placing case units into picking stock and to retrieve the ordered case units. As may be realized, the storage and retrieval system may be configured to allow random accessibility to the storage spaces. For example, all storage spaces in the storage structure **130** may be treated substantially equally when determining which storage spaces are to be used when picking and placing case units from/to the storage structure **130** such that any storage space of sufficient size can be used to store items. The storage structure **130** of the exemplary embodiments may also be arranged such that there is no vertical or horizontal array partitioning of the storage structure. For example, each multilevel vertical conveyor **150A**, **150B** is common to all storage spaces (e.g. the array of storage spaces) in the storage structure **130** such that any bot **110** can access each storage space and any multilevel vertical conveyor **150A**, **150B** can receive case units from any storage space on any level so that the multiple levels in the array of storage spaces substantially act as a single level (e.g. no vertical partitioning). The multilevel vertical conveyors **150A**, **150B** can also receive case units from any storage space on any level of the storage structure **130** (e.g. no horizontal partitioning). In the embodiments the storage and retrieval system may also be configured so that each multilevel vertical conveyor serves a predetermined area of the array of storage spaces.

The storage structure **130** may also include charging stations **130C** for replenishing, for example, a battery pack of the bots **110**. In the embodiments, the charging stations **130C** may be located at, for example, transfer areas **295** (FIG. 2) of the transfer deck **130B** so that the bots **110** can substantially simultaneously transfer items, for example, to and from a multilevel vertical conveyor **150A**, **150B** while being charged as described in U.S. Provisional Patent Application entitled "AUTONOMOUS TRANSPORT VEHICLE CHARGING SYSTEM" (Ser. No. 61/423,402) and filed on Dec. 15, 2010 (now U.S. patent application Ser. No. 13/326,823 filed Dec. 15, 2011), the disclosures of which are incorporated by reference herein in their entireties. The bots **110** and other suitable features of the storage and retrieval system **100** may be controlled by, for example, one or more central system control computers (e.g. control server) **120** through, for example, any suitable network **180**. The network **180** may be a wired network, a wireless network or a combination of a wireless and wired network using any suitable type and/or number of communication protocols. It is noted that, in one exemplary embodiment, the system control server **120** may be configured to manage and coordinate the overall operation of the storage and retrieval system **100** and interface with, for example, a warehouse management system **125**, which in turn manages the warehouse facility as a whole. The control server **120** may be substantially similar to that described in, for example, U.S. patent application Ser. No. 12/757,337, entitled "CONTROL SYSTEM FOR STORAGE AND RETRIEVAL SYSTEMS," the disclosure of which is incorporated by reference herein in its entirety.

Referring also to FIG. 2, an exemplary configuration of the storage and retrieval system **100** is shown. Other suitable exemplary configurations of storage and retrieval systems can be found in, for example, U.S. patent application Ser. No. 12/757,381, entitled "STORAGE AND RETRIEVAL SYSTEM" and filed on Apr. 9, 2010, and U.S. Provisional Patent Application entitled "WAREHOUSING SCALABLE STORAGE STRUCTURE" (Ser. No. 61/423,340) and filed on Dec. 15, 2010 (now U.S. patent application Ser. No. 13/326,674 filed Dec. 15, 2011), the disclosures of which are incorporated by reference herein in their entireties. It should

5

be understood that in the embodiments the storage and retrieval system may have any suitable configuration. As can be seen in FIG. 2, the storage and retrieval system 200 is configured, for exemplary purposes only, as a single-ended picking structure in which only one side of the system 200 has a transfer section or deck 130B. The single-ended picking structure may be used in, for example, a building or other structure having loading docks disposed only on one side of the building. In this example, the storage and retrieval system 200 includes transfer deck(s) 130B and picking aisles 130A that allow bots 110 to traverse an entirety of a level of the storage structure 130 on which that bot 110 is located for transporting items between any suitable storage locations/picking aisles 130A and any suitable multilevel vertical conveyors 150A, 150B. The multilevel vertical conveyors 150A, 150B provide transport of case units into the storage and retrieval system 200 through input workstations 210 and provide output of case units from the storage and retrieval system 200 through output workstations 220. In the embodiments, the storage and retrieval system 200 includes a first and second storage section 230A, 230B located side by side so that the picking aisles of each section are substantially parallel with each other and facing the same direction (e.g. towards transfer deck 130B). However, in the embodiments the storage and retrieval system may have any suitable number of storage sections arranged relative to each other in any suitable configuration.

Referring to FIGS. 3A and 3B an exemplary bot 110 is shown. In the embodiments the bot 110 includes a longitudinally extended frame 110F that has a first end 1500 and a second end 1501 where the longitudinal axis (e.g. Y-axis) 6000 extends from the first end 1500 to the second end 1501. At least one drive section 110D may be coupled to one of the first and/or second ends 1500, 1501 in any suitable manner for driving the bot 110 along the transfer deck(s) 130B and picking aisles 130A (FIG. 1). The drive 110D may include drive wheels, tracks or any other suitable drive mechanism for effecting travel of the bot along the transfer deck(s) 130B and picking aisles 130A. The other end 1500, 1501 of the bot 110 may have any suitable supports, such as caster wheels, fixed wheels, steerable wheels, and similar mechanisms for movably supporting the bot 110 as it travels along the transfer deck(s) 130B and picking aisles 130A. The bot 110 may have any suitable controller 1220 (FIG. 1) for effecting operation of the bot 110 and/or communication between the bot 110 and the control server 120 (FIG. 1). As may be realized the configuration of the bot shown in the drawings is merely exemplary and the bot may have any suitable configuration for carrying out the detection and positioning of case units relative to the bot 110 as described herein.

The frame 110F of the bot 110 may form a payload bed 1510 or other suitable holding structure that is configured to hold case units or any other suitable payload. The payload bed 1510 may be suitably sized for accepting (e.g. holding) any case unit (or pickface where a pickface is one or more case units that is/are to be picked and carried by the bot 110) that may be transferred into or removed from the storage and retrieval system 100. For example, in the embodiments the payload bed 1510 may be larger than an expected pick size (i.e. larger than the pickface the bot is expected to pick from, for example, a storage shelf of a storage section 230A, 230B or any other suitable component of the storage and retrieval system such as the multilevel vertical conveyors).

A fence 1510F or other suitable retaining device may be located at a side opening of the payload bed 1510. In one exemplary embodiment the fence 1510F may be attached to the frame 110F in any suitable manner such as with fasteners

6

or welding. In the embodiments the fence 1510F may also form part of the frame 110F or be of unitary construction with the frame 110F. The fence may include slots 1510FS disposed between stopping members 1510FM. The slots 1510FS may be configured to allow the fingers 1540 of the bot arm 1540A to extend through the fence 1510F in a substantially lowered position so that the fingers 1540 can be, for example, extended into a storage shelf below a case unit. The fence 1510F may be configured to extend above the payload bed 1510 to form a barrier that substantially prevents case units from exiting the payload bed 1510 once the case units are positioned on the payload bed 1510. In this example, the number of slots 1510FS is equal to the number of fingers 1540 but in alternate embodiments, the fence 1510F may be configured such that more than one finger 1540 passes through a single slot (e.g. the number of slots is less than the number of fingers). It should be noted that the fence may have any suitable configuration for preventing case units from exiting the payload area when the case units are carried by the bot 110. For example, the fence may be movable so that the stopping members are retractable such that when in an extended configuration the fence prevents the case units from exiting the payload area.

The payload bed 1510 may include any suitable payload supports for supporting the case units when the case units are carried by the bot 110. For exemplary purposes only, the payload supports may include rollers 1510R, where a rotational axis of each roller 1510R is disposed substantially transversely (or laterally) to the longitudinal axis 6000 of the bot 110. It is noted that the payload supports may also be belts, ball bearings or any other suitable supports. The rollers 1510R (or other suitable payload supports) may be inter-disposed with fingers 1540 of the bot 110 in an alternating manner. In the embodiments the rollers 1510R and the fingers 1540 may be arranged relative to each other in any suitable manner. In one example, the payload supports may be driven in any suitable manner for justifying the payload in the payload area as described in, for example, U.S. Provisional Patent Application entitled "BOT PAYLOAD ALIGNMENT AND SENSING" (Ser. No. 61/423,220) and filed on Dec. 15, 2010 (now U.S. patent application Ser. No. 13/327,040 filed on Dec. 15, 2011), the disclosures of which are incorporated by reference herein in their entireties.

The fingers 1540 of the bot arm 1540A extend laterally in the direction of arrow 1550 relative to the longitudinal axis 6000 of the bot. The fingers 1540 are also capable of movement in the direction of arrow 1673 (e.g. in a direction substantially perpendicular to the direction 1550 of extension and retraction of the fingers). The fingers may be driven by any suitable drive for lifting the pickfaces over the fence 1510F and into/out of the payload bed 1510 of the bot 110.

A case unit contact member 1530 may be movably located at least partially within the payload area. The case unit contact member 1530 may be driven laterally in the direction of arrow 1550 by any suitable drive. In this exemplary embodiment both of the case unit contact member 1530 and the fingers 1540 are configured to move laterally in the direction of arrow 1550. The case unit contact member 1530 may be configured to move along rails 1530R (FIGS. 7A and 7B). The rails may be mounted to the frame 110F in any suitable manner for guiding the movement of at least the case unit contact member 1530. In the embodiments the movement of the case unit contact member 1530 may be guided in any suitable manner. For exemplary purposes only, referring to FIGS. 7A and 7B, the case unit contact member 1530 may have slide members 1530D for movably coupling the case unit contact member 1530 to the rails 1530R. In the embodiments the case unit

contact member **1530** may be movable independent of the fingers **1540** in the direction of arrow **1550** for engaging case units disposed on the payload bed **1510**. The fingers **1540** may be releasably coupled to the case unit contact member **1530** in any suitable manner such that the fingers **1540** are extended using the case unit contact member drive system. Suitable examples of the bot transfer arm, fingers and transfer arm drive system can be found in U.S. Provisional Patent Application entitled "AUTOMATED BOT TRANSFER ARM DRIVE SYSTEM," (Ser. No. 61/423,388) and filed on Dec. 15, 2010 (now U.S. patent application Ser. No. 13/326,993 Dec. 15, 2011) and U.S. Provisional Patent Application entitled "AUTOMATED BOT WITH TRANSFER ARM" (Ser. No. 61/423,365) and filed on Dec. 15, 2010 (now U.S. patent application Ser. No. 13/326,952 filed Dec. 15, 2011), previously incorporated by reference.

Still referring to FIGS. 3A and 3B and also to FIGS. 4, 5, 5A and 5B, the at least one drive section **110D** may be connected to the frame in any suitable manner. In one aspect the drive section **110D** may be connected to the frame by any suitable movable coupling system. In the embodiments the movable coupling system may be a suspension system that may pivotally (or otherwise movably) couple the drive section **110D** to the frame **110F** in any suitable manner to allow for relative rotation between the at least one drive section **110D** and the frame **110F**. It should be noted that while a pivotal coupling is shown and described that in other aspects the coupling may be, for exemplary purposes only, any suitable articulated coupling including but not limited to linearly movable couplings, rotatable couplings or a combination thereof. As may be realized, the bot may be supported at four points (e.g. one wheel **1261**, **1262**, **1211**, **1212** being located at substantially each corner of the bot). If all four support wheels were rigidly connected to the frame **110F** and the bot were to travel over bumps or other raised/uneven structures on, for example, the travel surface of the transfer decks **130B** and/or picking aisles **130A** one or more wheels of the bot may be lifted off of the travel surface causing, for example, a loss of wheel traction. As may also be realized, a position of the bot within the storage and retrieval system **100** may be determined at least in part with any suitable wheel odometry system, as described in e.g. U.S. Provisional Patent Application entitled "BOT POSITION SENSING" the disclosure of which was previously incorporated herein by reference, such that a loss of wheel traction may cause an incorrect odometry reading. The movable connection between the at least one drive section **110D** and the frame **110F** may substantially prevent the drive wheels **1211**, **1212** from lifting off of the travel surface such that accurate bot positioning can be determined.

In the embodiments, the frame **110F** may include a pivot or articulation member **400**. The pivot member **400** may be located substantially in line with the longitudinal axis **6000** of the bot **110** such that the weight of the bot (and any payload thereon) may be centrally supported at the end **1501** of the bot **110**. It is noted that the pivot member **400** may be suitably located at any location on the end **1501** of the bot frame **110F**. The pivot member may be integrally formed with the frame **110F** or affixed to the frame in any suitable manner. In this example the pivot member **400** may include any suitable recess or aperture **400R** configured to accept a corresponding pivot axle **500** of the at least one drive section **110D**.

The at least one drive section **110D** may include a pivot axle **500** configured to be received within the recess **400R** of the pivot member **400** or the frame **110F** may include the pivot axle and the drive section **110D** may include the pivot member. As may be realized, in the embodiments the frame and

drive section may have any suitable structure for allowing the drive section to pivot relative to the frame. In this example, the pivot axle **500** may be pivotally retained within the pivot member **400** in any suitable manner such as by clips, bolts, snaps or any other suitable retention devices. The pivot axle **500** and pivot member **400** may be configured such that the drive section **110D** pivots axially in the direction of arrow **550** with respect to the longitudinal axis **6000** of the frame **100F**. The connection between the drive section **110D** and the frame **110F** may also be configured to allow drive section **110D** and the frame **110F** to pivot relative to each other in any suitable direction(s).

In the embodiments the drive section **110D** may include one or more guide members **530**. The guide members **530** may be wheels, sliders or any other suitable structure that, for example, engages a surface **535** of the frame **110F** when the drive section **110D** and the frame **110F** are coupled to each other through the pivotal coupling **510** (e.g. formed by pivot axle **500** and pivot member **400**). The frame **110F** may also include the guide members **530** such that the guide members engage a surface of the drive section **110D** when the frame **110F** and drive section **110D** are movably coupled to each other. In this example the guide members **530** may be mounted to the drive section **110D** so that the guide members **530** allow the relative pivotal (or otherwise) movement between the drive section **110D** and the frame **110F** while in part substantially maintaining a substantially rigid longitudinal axis of the bot **110**. For example, in the embodiments the guide members **530** are laterally spaced (e.g. along the X-axis) from the pivot axis **510P** of the pivotal coupling **510** by any suitable distance X_1 , X_2 . The distance X_1 , X_2 between the pivot axis **510P** and the guide members **530** may substantially prevent (through contact between the guide members **530** and the surface **535** of the frame) yawing motion (e.g. in the direction of arrow **598** in the X-Y plane) between the drive section **110D** and the frame **110F**. At least one of the guide members **530** may also be vertically spaced (e.g. along the Z-axis) from the pivot axis **510P** by any suitable distance Z_1 , Z_2 . The distance Z_1 , Z_2 between the pivot axis **510P** and the at least one of the guide members **530** may substantially prevent (through contact between the one of the guide members **530** and the surface **535** of the frame) pitching motion (e.g. in the direction of arrow **599** in the Y-Z plane) between the drive section **110D** and the frame **110F**. In this example, the guide members **530A-530D** may be located substantially at corners of an interface surface **110DS** of the drive section **110D** such that two guide members **530A**, **530B** are vertically spaced above the pivot axis **510P** by a distance Z_1 and two guide members **530C**, **530D** are vertically spaced below the pivot axis **510P** by distance Z_2 . Alternatively, it is noted that all of the guide members **530A-530D** may be located above the pivot axis or below the pivot axis. The guide members **530A**, **530D** may be laterally spaced from the pivot axis (on a first side of the pivot axis) by distance X_1 and guide members **530B**, **530C** may be laterally spaced from the pivot axis (on a second opposite side of the pivot axis) by distance X_2 . In the embodiments there may be any suitable number of guide members arranged (e.g. spaced from the pivot axis) to prevent yawing and pitching motion between the drive section **110D** and the frame **110F**.

In the embodiments the axial stability (e.g. in yaw and pitch) of the coupled drive section **110** and frame **110F** may be provided through one or more of the guide members **530A-530D** and the connection between the pivot member **400** and pivot axle **500**. For example, in one exemplary embodiment the pivot axle **500** may be axially secured within the pivot member **400** so that the guide members **530A-530D** are held

substantially against the surface **535** of the frame. One or more of the guide wheels **530**, the pivot axle **500** and pivot member **400** may also be adjustable in the longitudinal or X-direction to take up or substantially eliminate any relative movement in the X-Y and Y-Z (e.g. yaw and pitch) planes between the drive section **110D** and the frame **110F**. It is noted that the guide wheels may be held against the surface **535** of the frame **110** in any suitable manner for providing a substantially rigid longitudinal coupling between the drive section **110D** and the frame **110F**. As may be realized, the guide members **530** and/or the pivotal coupling **510** may only allow relative rotation (e.g. roll) between the drive section **110D** and the frame **110F** in the direction of arrow **550** in the X-Z plane. In other aspects the coupling between the drive section and frame may allow any suitable relative movement between drive section and the frame.

As may be realized the rotation or pivoting between the drive section **110D** and the frame **110F** in the direction of arrow **550** (in the X-Z plane) may be limited in any suitable manner. Referring to FIGS. **5**, **7A** and **7B** in one exemplary embodiment, protruding members **560**, **561** may extend from interface surface **110DS** of the drive section **110D**. In this example, the protruding members **560**, **561** are located at opposite lateral ends of the drive section **110D** but the protruding members may be located at any suitable position for limiting pivotal travel between the drive section **110D** and the frame **110F**. The protruding members **560**, **561** may be any suitable members configured to engage, for example, a recess or groove **560G** such as, for example, pins, bushings, threaded rods, studs, etc. It is noted that while the protruding members **560**, **561** are described with respect to protruding member **560** the protruding member **561** is substantially similar to protruding member **560**. In this example the protruding member **560** may be a stud or pin. A suitable bushing **560B** may be connected to the protruding member **560**. In one example, the protruding member **560** and the bushing **560B** may be integrally formed with each other. In another example, the bushing **560B** may be fixed to the protruding member **560** by mechanical or chemical fasteners, by an interference fit between the two or in any other suitable manner. In the embodiments the bushing **560B** may be configured to substantially cushion the pivoting travel of the drive section **110D** as the drive section **110D** reaches its travel limits. Alternatively the bushing may provide a substantially hard stop for the pivoting drive section **110D**. The travel limits of the drive section **110D** may be effected by recesses or grooves **560G** formed in the frame **110F** that correspond to each of the protruding members **560**, **561**. The bushing **560B** for each of the protruding members **560**, **561** and the corresponding grooves **560B** may be configured such that when the bot **110** is on a substantially level surface the bushing **560B** is spaced from an end of the corresponding groove **560B** by any suitable predetermined distance **N**. The bushings **560B** and grooves **560G** may be sized such that the bushing moves substantially in the direction of arrow **710** within the groove **560G** during pivoting movement of the drive section **110D** substantially without interference. Contact between the bushing **560B** and the end of the groove **560G** limits the travel (e.g. pivotal movement) between the drive section **110D** and the frame **110F**.

Referring to FIGS. **3B**, **6A**, **6B**, **6C**, **6D**, **7A** and **7B** the relative pivotal movement between the drive section **110D** and the frame **110F** may allow movement between the frame **110F** and the drive section **110D** as the bot arm **1540A** (FIG. **3A**) is extended laterally to pick/place a pickface from one of the storage shelves of the storage sections **230A**, **230B** or multilevel vertical conveyors **150A**, **150B**. The bot **110** may

include a locking system or lockout mechanism having one or more locking devices **600** configured to passively lock out the bot suspension for substantially preventing relative movement between the drive section **110D** and frame **110F** as the bot arm **1540A** is extended laterally or in any other suitable direction (e.g. extension of the bot arm **1540A** passively causes a locking of the suspension). Though the embodiments are described with respect to the passive locking of the suspension when the arm is extended, in other aspects the locking devices **600** may be configured to actively lock the suspension in any suitable manner independent of the arm position. The locking device **600** may be located any suitable predetermined distance from the pivot axis **510P**. In one example one or more locking devices **600** may be located substantially at or adjacent a respective side edge **110E1**, **110E2** of the frame **110F**. While a locking device **600** is shown adjacent each of the edges **110E1**, **110E2**, a single locking device may be located along only one of the edges **110A1**, **110E2**. Still any suitable number of locking devices **600** may be located at any suitable location(s) relative to, for example, the pivot axis **510P**.

In this example, the locking device **600** may include a body **601**, a resilient member **602** and a lever member **603**. The body may have any suitable configuration and is shown in the Figs. as having a substantially rectangular shape for exemplary purposes only. In this example the body may be configured for attachment to the frame **110F** but, the body may also be configured for attachment to the drive section **110D**. The body **601** may include a recess **602R** suitably sized so that the resilient member **602** may be inserted into the recess **602R**. In this example, the resilient member **602** may be an extension spring but in alternate embodiments the resilient member **602** may be any suitable resilient member such as a leaf spring, compression spring or torsion spring and the body **601** may be suitably configured for interfacing with or housing the resilient member in any suitable manner. The lever member **603** may be pivotally mounted to the body **601** in any suitable manner such as through, for exemplary purposes only, a pivot pin **610**. The lever member **603** may have a compound surface having a first surface **603A** and a second surface **603B** that engages a cam **751** as described below and a surface **603E** that engages an engagement member **750** as will also be described below. The body **601** may be configured so that the lever member **603** pivots in the direction of arrow **620** which may be substantially parallel with the interface surfaces **535**, **110DS** of the frame **110F** and drive section **110D** when the body is mounted to, for example, the frame **110F**. The resilient member **602** may be positioned relative to the lever member **603** and/or the lever member **602** may be configured such that the resilient member **602** engages the lever member **603** for rotating the lever member **603** in the direction of arrow **798** towards an aperture **611** formed in the body **601** so that the locking device **600** is biased in a suspension locked position (e.g. in the direction of arrow **798**) when the arm is extended and retraction of the arm acts against the force provided by the resilient member **602** for locking the suspension so that the arm moves in the direction of arrow **799**.

The locking system may also include an engagement member **750** corresponding to each of the locking devices **600**. The engagement member **750** may be configured for attachment to, for example, the drive section **110D** such that the engagement member **750** extends from the interface surface **110DS**. The engagement member **750** may be positioned so that it extends through the aperture **611** in the body for interfacing with the surface **603E** of the lever member **603**. The engagement member **750** and/or the aperture **611** may be configured

11

to allow movement of the engagement member 750 within the aperture 611 as the drive section 110D and frame 110F pivot relative to one another.

One or more cams or idlers 751 may be rotatably mounted to the frame 110F. Each cam 751 may be positioned at any suitable location of the frame 110F for interfacing with, for example, surfaces 603A, 603B (or any other suitable surface) of a respective one of the lever members 603 of the one or more locking devices 600. For example, the cam 751 may move with, for example, a respective one of the slide members 1530D as the bot arm 1540A is extended and retracted. As the bot arm 1540A is extended the cam 751 moves in the direction of arrow 798 moving from surface 603B to surface 603A and eventually off of the lever 603 allowing the lever member to pivot in the direction of arrow 798 towards the aperture 611 for locking the suspension of the bot 110. As may be realized the force exerted on the lever member 603 by the resilient member 602 may hold the lever member against the surface of the cam 751 so that as the cam 751 moves the lever member is moved towards and away from the aperture 611 for locking and releasing the suspension of the bot 110. When the bot arm 1540A is retracted the cam 751 moves in the direction of arrow 799 so that the cam 751 engages the surface 603A and then the surface 603B of the lever 603 causing the lever to pivot in the direction of arrow 799 for releasing the suspension of the bot 110. As seen best in FIG. 6D, when the cam 751 is engaged with the surface 603B of the lever, the surface 603B of the lever member 603 is oriented in such a way so that the cam 751 remains substantially in place substantially without any outside influence (such as from motors or clips) due to, for example, the normal force between the cam 751 and the surface 603B provided by the resilient member 602, which is overcome when the bot arm is extended. In alternate embodiments, the cam 751 may be stationary (e.g. does not move with, for example, the slide members 1530D) and driven by any suitable drive system such that the driven rotation of the cam causes the pivoting movement of the lever 603 for locking and unlocking the bot suspension.

As described above, the engagement member 750 extends through the aperture for interfacing with the lever member 603. As movement of the cam 751 in the direction of arrow 798 allows movement of the lever member 603 in the direction of arrow 798, the surface 603E of the lever member 603 contacts the engagement member 750 and pinches or clamps the engagement member 750 against any suitable surface of the body 601. For example, the engagement member 750 may extend into a block member 601B of the body 601 such that at least a portion of the engagement member 750 is located between a surface of the block member 601B and the lever member 603 (e.g. the engagement member is pinched or clamped between the lever member and the surface of the block as the cam is rotated). The pinching or clamping force exerted on the engagement member 750 may be a predetermined force sufficient to substantially rigidly hold the drive section 110D in a predetermined position relative to the frame 110F (e.g. substantially prevent relative pivoting between the frame and drive section such that the drive section and frame form a single substantially stiff structure) as the bot arm 1540A is laterally extended to, for example, transfer pick-faces between the bot 110 and a storage shelf or multilevel vertical conveyor.

In the embodiments, the one or more cams 751 may be suitably connected to any suitable bot arm drive system 770 for passively locking the suspension of the bot 110. For example, the connection between the one or more cams 751 and the bot arm drive system 770 may cause operation of the

12

locking device 600 as the bot arm 1540A is extended for passively/automatically locking the suspension of the bot. The cam 751 may also be driven by an independently operable drive system so that the bot suspension can be actively locked/unlocked independent of the bot arm position. In the embodiments, when the bot arm 1540A is in a predetermined retracted or homed position the locking device 600 is automatically released and the drive section 110D and frame 110F are allowed to pivot (or otherwise move) relative to one another. For example, during operation of the bot 110, the bot 110 may traverse the picking aisles 130A and transfer deck 130B with the bot arm 1540A in a homed (e.g. retracted) position. With the bot arm 1540A in the homed position the bot suspension is unlocked and the drive section 110D and frame 110F are free to pivot relative to one another allowing the suspension to conform to the travel surfaces of the picking aisles 130A and transfer deck 130B. As the bot arm 1540A is extended the cam 751 is passively moved (by virtue of its connection to the bot arm drive system 770) for allowing the lever member 603 to move in the direction of arrow 798 for pinching or clamping the engagement member 750 and passively locking the bot suspension so that the drive section 110D and frame 110F form a single substantially rigid or stiff structure substantially eliminating any rotation or tipping of the frame 110F that may cause the extended arm 1540A to tip relative to a surface on which a pickface is located or being transferred to. As the bot arm 1540 is retracted to the home position the cam 751 is passively moved for moving the lever member 603 in the direction of arrow 799 for releasing the engagement member 750 and passively unlocking the bot suspension. It is noted that the cam may be passively or actively driven in any suitable manner for causing operation of the locking device.

In a first exemplary embodiment an autonomous transport robot for transporting a payload is provided. The autonomous transport robot includes a drive section assembly having at least one motor and a pair of drive wheels coupled to the motor, a frame configured to support a payload, a transfer arm connected to the frame and configured for an autonomous transfer of payload to and from the frame, and a suspension system movably connecting the drive section assembly and the frame allowing relative movement between the frame and the drive section assembly.

In accordance with the first exemplary embodiment, the suspension lockout device is configured such that the suspension is free to move when the transfer arm is in a retracted position.

In accordance with the first exemplary embodiment, the suspension is configured to maintain drive wheels of the drive section in substantial contact with a travel surface on which the autonomous transport vehicle is travelling.

In accordance with a first aspect of the first exemplary embodiment the suspension system includes a pivot member mounted to one of the frame and drive section and a pivot axle mounted to the other one of the frame and drive section, where the pivot axle and pivot member are configured to engage each other to form a pivot coupling between the frame and drive section.

In accordance with the first aspect of the first exemplary embodiment one or more guide members are connected to one of the frame and drive section, the guide members being configured to engage an interface surface of the other one of the frame and drive section and at least in part to substantially prevent relative yaw and pitch between the frame and drive section.

In accordance with a second aspect of the first exemplary embodiment the autonomous transport robot further includes

13

a suspension lockout device connected to one or more of the frame and drive section. The suspension lockout device being configured to passively lock the suspension system as the transfer arm is extended from the frame where locking of the suspension system substantially prevents relative pivoting movement between the drive section and the frame.

In accordance with the second aspect of the first exemplary embodiment the lockout device includes an engagement member mounted to one of the frame and drive section, a locking device mounted to the other one of the frame and drive section and an actuation member configured to actuate the locking device causing the locking device to engage the engagement member.

In accordance with the second aspect of the first exemplary embodiment the lockout device includes a body and a lever member pivotally mounted to the body, wherein the engagement member extends between the body and lever member and the body and lever member are configured such that actuation of the locking device causes the engagement member to be clamped between the lever member and body.

In accordance with the second aspect of the first exemplary embodiment the lockout device includes a resilient member configured to move the lever member away from the engagement member for at least in part unlocking the suspension.

In accordance with the second aspect of the first exemplary embodiment the actuation member comprises a cam connected to a drive system of the transfer arm, wherein the cam is configured to be passively rotated during extension of the transfer arm.

In accordance with a second exemplary embodiment a suspension lockout system for an autonomous transport vehicle is provided. The suspension lockout system includes an engagement member mounted to one of a frame and drive section assembly of the autonomous transport vehicle, where the frame is configured to support a payload and the drive section assembly includes at least one motor and a pair of drive wheels coupled to the motor, and a locking device mounted to another one of the frame and drive section assembly of the autonomous transport vehicle, wherein a suspension system of the autonomous transport vehicle connecting the frame to the drive section assembly is configured to allow pivotal movement between the frame and drive section assembly and the suspension lockout system is configured to release the suspension system for unrestricted movement between the frame and drive section assembly when the transfer arm is in a retracted position and to be automatically locked when the transfer arm is extended from the retracted position, and wherein locking of the suspension lockout system substantially prevents pivotal movement between the frame and drive section.

In accordance with a first aspect of the second exemplary embodiment the suspension lockout system the locking device includes a body and a lever member pivotally mounted to the body, wherein the engagement member extends between the body and lever member and the body and lever member are configured such that actuation of the locking device causes the engagement member to be clamped between the lever member and body.

In accordance with the first aspect of the second exemplary embodiment the suspension lockout system further includes a cam connected to the transport arm drive system, wherein the cam is configured to be passively rotated during extension of the transfer arm and to engage the lever member for causing clamping of the engagement member.

In accordance with the second exemplary embodiment the locking device includes a resilient member configured to

14

move the lever member away from the engagement member for at least in part unlocking the suspension.

In accordance with a third exemplary embodiment a suspension system for an autonomous transport vehicle is provided. The suspension system includes an articulated coupling configured to allow rolling movement between a frame and a drive section assembly of the autonomous transport vehicle along a common longitudinal axis where the frame is configured to support a payload and the drive section assembly includes at least one motor and a pair of drive wheels coupled to the motor, and a suspension locking system configured to automatically substantially prevent the rolling movement when an extendable transfer arm is moved from a retracted position, where the extendable transfer arm is configured to move between the retracted position and an extended position relative to the frame.

In accordance with the third exemplary embodiment the suspension locking system is configured to automatically release the articulated coupling to allow the rolling movement when the arm is moved to the retracted position.

In accordance with the third exemplary embodiment the suspension system is configured to maintain drive wheels of the drive section assembly in substantially continuous contact with a travel surface on which the autonomous transport vehicle is travelling.

In accordance with the third exemplary embodiment the suspension system further includes one or more guide members mounted to one of the frame and drive section assembly at an interface between the frame and guide section, the one or more guide members being configured to substantially prevent yaw and pitch motion between the frame and drive section.

In accordance with a first aspect of the third exemplary embodiment the suspension locking system includes an engagement member mounted to one of the frame and drive section assembly, a body mounted to another one of the frame and drive section and a lever member pivotally mounted to the body, wherein the engagement member extends between the body and lever member and the body and lever member are configured such that actuation of the suspension locking system causes the engagement member to be clamped between the lever member and body.

In accordance with the first aspect of the third exemplary embodiment the suspension locking system includes a resilient member configured to move the lever member away from the engagement member for at least in part unlocking the articulated coupling.

In accordance with the first aspect of the third exemplary embodiment the suspension locking system further includes a cam configured to engage the lever member for actuating the suspension locking system, wherein the cam is passively connected to a drive system of the extendable transfer arm.

It should be understood that the exemplary embodiments disclosed herein can be used individually or in any suitable combination thereof. It should also be understood that the foregoing description is only illustrative of the embodiments. Various alternatives and modifications can be devised by those skilled in the art without departing from the embodiments. Accordingly, the present embodiments are intended to embrace all such alternatives, modifications and variances that fall within the scope of the appended claims.

What is claimed is:

1. An autonomous transport robot for transporting a payload, the autonomous transport robot comprising:
 - a drive section assembly having at least one motor and a pair of drive wheels coupled to the at least one motor;
 - a frame configured to support a payload;

15

a payload justification system configured for at least one degree of freedom payload positioning within the frame; and

a suspension system movably connecting the drive section assembly and the frame allowing relative movement between the frame and the drive section assembly.

2. The autonomous transport robot of claim 1, wherein the suspension is configured to maintain drive wheels of the drive section in substantial contact with a travel surface on which the autonomous transport vehicle is travelling.

3. The autonomous transport robot of claim 1, wherein the suspension system includes a pivot member mounted to one of the frame and drive section and a pivot axle mounted to the other one of the frame and drive section, where the pivot axle and pivot member are configured to engage each other to form a pivot coupling between the frame and drive section.

4. The autonomous transport robot of claim 3, wherein one or more guide members are connected to one of the frame and drive section, the guide members being configured to engage an interface surface of the other one of the frame and drive section and at least in part to substantially prevent relative yaw and pitch between the frame and drive section.

5. The autonomous transport robot of claim 1, further comprising a suspension lockout device connected to one or more of the frame and drive section, the suspension lockout device being configured to passively lock the suspension system as the payload justification system is extended from the frame where locking of the suspension system substantially prevents relative pivoting movement between the drive section and the frame.

6. The autonomous transport robot of claim 5, wherein the suspension lockout device is configured such that the suspension is free to move when the payload justification system is in a retracted position.

7. The autonomous transport robot of claim 5, wherein the lockout device includes an engagement member mounted to one of the frame and drive section, a locking device mounted to the other one of the frame and drive section and an actuation member configured to actuate the locking device causing the locking device to engage the engagement member.

8. The autonomous transport robot of claim 7, wherein the lockout device includes a body and a lever member pivotally mounted to the body, wherein the engagement member extends between the body and lever member and the body and lever member are configured such that actuation of the locking device causes the engagement member to be clamped between the lever member and body.

9. The autonomous transport robot of claim 8, wherein the lockout device includes a resilient member configured to move the lever member away from the engagement member for at least in part unlocking the suspension.

10. The autonomous transport robot of claim 7, wherein the actuation member comprises a cam connected to a drive system of the transfer arm, wherein the cam is configured to be passively rotated during extension of the transfer arm.

11. The autonomous transport robot of claim 1, wherein the payload justification system is configured for two degree of freedom payload positioning within the frame.

12. An autonomous transport vehicle for transporting a payload, the autonomous transport vehicle comprising:

a frame having at least four corners and at least four support wheels, the four support wheels being distributed at least proximate the at least four corners of the frame to support the frame on and contact a travel surface on which the autonomous transport vehicle travels, where the frame defines a payload support section and a drive

16

section coupled to each other by a locking articulated coupling system having an articulated coupling lockout device;

a payload justification system connected to the payload support section and configured for at least one degree of freedom payload positioning within the frame;

wherein the drive section has a motor and at least two support wheels of the at least four support wheels are disposed on opposite sides of the drive section, the at least two support wheels being drive wheels coupled to the motor.

13. The autonomous transport vehicle of claim 12, wherein the locking articulated coupling system comprises:

an articulated coupling configured to allow rolling movement between the payload support section and the drive section along a common longitudinal axis; and

the articulated coupling lockout device being configured to automatically substantially prevent the rolling movement when the payload justification system is moved from a retracted position, where the payload justification system is configured to move between the retracted position and an extended position relative to the payload support section.

14. The autonomous transport vehicle of claim 13, wherein the articulated coupling lockout device is configured to automatically release the articulated coupling to allow the rolling movement when the payload justification system is moved to the retracted position.

15. The autonomous transport vehicle of claim 13, wherein the articulated coupling lockout device is connected to one or more of the payload support section and the drive section, the articulated coupling lockout device being configured to passively lock the articulated coupling as the payload justification system is extended from the payload support section.

16. The autonomous transport vehicle of claim 12, wherein the articulated coupling lockout device includes an engagement member mounted to one of the payload support section and the drive section, a locking device mounted to the other one of the payload support section and the drive section and an actuation member configured to actuate the locking device causing the locking device to engage the engagement member.

17. The autonomous transport vehicle of claim 16, wherein the articulated coupling lockout device includes a body and a lever member pivotally mounted to the body, wherein the engagement member extends between the body and the lever member, the body and the lever member being configured such that actuation of the locking device causes the engagement member to be clamped between the lever member and the body.

18. The autonomous transport vehicle of claim 17, wherein the articulated coupling lockout device includes a resilient member configured to move the lever member away from the engagement member for at least in part unlocking the articulated coupling.

19. The autonomous transport vehicle of claim 16, wherein the actuation member comprises a cam connected to a drive system of the payload justification system, wherein the cam is configured to be passively rotated during extension of the payload justification system.

20. The autonomous transport vehicle of claim 12, wherein the locking articulated coupling system is configured to maintain the drive wheels of the drive section in substantial contact with the travel surface.

21. The autonomous transport vehicle of claim 12, wherein the locking articulated coupling system includes a pivot member mounted to one of the payload support section and

17

the drive section and a pivot axle mounted to the other one of the payload support section and the drive section, where the pivot axle and pivot member are configured to engage each other to form a pivot coupling between the payload support section and the drive section.

22. The autonomous transport vehicle of claim 12, wherein the payload justification system is configured for two degree of freedom payload positioning within the frame.

23. A method comprising:

providing an autonomous transport robot that includes
a drive section assembly having at least one motor and a
pair of drive wheels coupled to the at least one motor,
a frame for supporting a payload, and
a payload justification system configured for at least one
degree of freedom payload positioning within the frame;
and

movably connecting the drive section and frame with a
suspension system for allowing relative movement
between the frame and the drive section assembly where

18

the relative movement is locked and unlocked with the
payload justification system.

24. The method of claim 23, further comprising substan-
tially preventing, at least in part, relative yaw and pitch
between the frame and drive section with one or more guide
members connected to one of the frame and drive section,
where the guide members engage an interface surface of the
other one of the frame and drive section.

25. The method of claim 23, wherein the relative move-
ment is passively locked as the payload justification system is
extended from the frame where locking of the relative move-
ment substantially prevents relative pivoting movement
between the drive section and the frame.

26. The method of claim 25, wherein the suspension is free
to move when the payload justification system is in a retracted
position.

27. The method of claim 23, wherein the payload justifi-
cation system is configured for two degree of freedom pay-
load positioning within the frame.

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